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RSJ07778GB

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3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

Land Instruments International Limited
Wreakes Lane,
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Sheffield,
S18 6DJ
United Kingdom

03949069001
Patents ADP number *(if you know it)*

If the applicant is a corporate body, give the country/state of its incorporation

United Kingdom

4. Title of the invention

Thermal Imaging System

5. Name of your agent *(if you have one)*

Gill Jennings & Every

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

Broadgate House
7 Eldon Street
London
EC2M 7LH

Patents ADP number *(if you know it)*

745002

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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Claim *(s)*	4
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Any other documents *(please specify)*	NO

11. For the applicant
Gill Jennings & Every

I/We request the grant of a patent on the basis of this application.

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Date 25/04/03

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THERMAL IMAGING SYSTEM

This invention relates to a thermal imaging system for generating high precision temperature images of a scene.

Thermal imagers provide two dimensional temperature images of a scene. Typically, such devices observe and measure infrared emission from the scene, thus providing a measure of temperature without being in contact with the source. Infrared energy is emitted by all materials at temperatures above absolute zero. This energy travels in the form of electromagnetic waves with wavelengths typically in the range 0.7 microns to 20 microns. When an infrared ray is intercepted by a body which is not transparent to the infrared spectrum, it induces electronic transitions or its energy is converted into heat and the infrared rays may be observed.

On striking a material surface, part of the infrared energy will be absorbed, some will be reflected and the remainder transmitted through the object. Of the energy absorbed by the material, a proportion may be re-emitted. Together, these phenomena determine the "emissivity" of the material. A "black body" is a hypothetical object or system which does not reflect or transmit any infrared energy incident upon it. All such radiation is absorbed and the black body re-radiates energy characteristic of the black body system only. A true black body has an emissivity of 1 but the nearest that can be achieved in practice is 0.998, using an infrared opaque cavity with a small aperture.

Infrared imaging systems convert the energy transmitted in the infrared spectrum into a visible light image. This is generally termed "thermography" and has applications in a wide range of fields ranging from monitoring metal melts to night vision or security imaging.

Other applications include medical imaging, process control and non-destructive testing. Generally speaking, such applications fall into one of two categories. Surveillance applications such as criminal tracking or building inspection require high resolution images but low accuracy temperature measurements are acceptable. On the other hand, industrial and medical uses require radiometric images which provide quantitative readings of the temperatures observed.

Several types of infrared sensing devices are available. A spot or point radiometer measures radiation from one particular point at a time, and outputs a reading showing the temperature of that point. A thermal line scanner shows radiant temperature along a line. A thermal imaging camera produces a temperature map of the full scene. Typically, thermal imaging cameras make use of a focal plane array (FPA) detector to observe the infrared energy emitted from a scene. FPA detectors consist of an array of detectors positioned in the plane at which the image of the scene is focussed. This results in high resolution thermal images. Conventional radiometric FPAs use photon detectors which effectively count infrared photons over a short period of time. Typical detectors are fabricated from mercury cadmium telluride material in various compositions. In typical industrial use, these detectors have a long wavelength sensitivity cut-off at about 5 microns and must be cooled to temperatures of approximately -80°C. Such imaging devices based on photon detectors achieve high accuracy but are complex and expensive. Some industrial applications benefit from sensing at longer wavelengths, for example in the wavelength region 8 to 14 microns. Photon detector arrays can be made to operate at these wavelengths but require even more cooling, typically down to -200°C and the resulting instruments are even more complex and expensive.

A new generation of imagers has recently emerged which use uncooled focal plane array detectors. An array of, typically, bolometers is located in the camera's focal plane. On striking the bolometer, an incident infrared ray will cause an increase in the temperature of the bolometer and therefore a change in its electrical resistance. The resistance of the bolometer may be measured and the incident infrared energy calculated. Detectors other than bolometers may be used, for example thermopiles or pyroelectrics. They are referred to as thermal detectors since the detection process involves the conversion of infrared energy to heat. The main advantage of a thermal detector array is that it may be operated at close to room temperature. The complex cooling systems of previous FPAs are therefore not required and the resulting thermal imaging device is simpler, smaller and less expensive. Thermal detectors are also wideband; that is they respond equally to infrared radiation of all wavelengths, in particular they do not exhibit the sharp long-wavelength cut-off typical of photon detectors.

Thermal imagers based on uncooled FPA detectors are very sensitive but not very radiometric: the relation between the image and the temperatures in the scene is only semi-quantitive. In part, this is due to the fact that uncooled FPA detectors are typically operated at long wavelengths, typically 8 to 14 microns and as a consequence are influenced by emissions from the internal parts of the camera. As such, imaging devices based on this technology are useful for surveillance but are not suitable for use in industrial applications which require more accurate knowledge of the measured temperatures. It would be advantageous to improve the accuracy of the image output from an uncooled FPA camera, resulting in a highly quantitative temperature imaging apparatus which is inexpensive and suitable for industrial use. One application in which such an apparatus would be

particularly desirable is monitoring the temperature of metal heat exchangers during testing. Conventional techniques require thermometers to be in contact with the metal heat exchanger which, in practice, allows only a small number of point measurements. What is needed is an apparatus which produces a detailed, spatially-resolved, temperature map with high temperature accuracy.

In accordance with the present invention, a thermal imaging system for quantitative thermal mapping of a scene comprises a thermal imaging device; a first heat source of known temperature and emissivity, located within the scene viewed by the thermal imaging device; and a processor adapted to generate a calibrated temperature map of the scene from the data supplied by the thermal imaging device, based on the known temperature of the heat source.

By providing the imaging system with a known temperature reference point, the data supplied by the thermal imaging device may be calibrated resulting in a highly radiometric output image. This makes it possible to use uncooled focal plane array detector technology to produce accurate temperature measurements suitable for industrial applications, whilst remaining inexpensive and straightforward to use.

The invention further provides a method of generating a quantitative thermal map of a scene, the method comprising positioning a first heat source of known temperature and emissivity within the scene; imaging the scene using a thermal imaging device; and generating a calibrated temperature map of the scene, based on the known temperature of the heat source, using a processor.

Preferably, the thermal imaging system further comprises a second heat source of known temperature and emissivity, located within the scene viewed by the thermal

imaging device and the processor is adapted to generate the calibrated temperature map from the data supplied by the thermal imaging device, based on the known temperatures of both the first and the second heat sources. By providing the system with two known temperature reference points, the processor is able to more accurately determine the correction required to calibrate the image.

Generally, the thermal imaging system further comprises means for measuring the temperature of the or each heat source and communicating the temperature to the processor. The temperature of the heat sources may be measured by various means such as a contact sensor or an infrared thermometer. The temperatures may be adjustable by electronic means such as resistance heating means or a device operating on the Peltier principle. Preferably, the control of each heat source is effected by electronic circuitry local to that heat source with the set-point temperature communicated from the processor. Typically, the temperatures of the heat sources will be controlled to just above and just below the temperatures of interest in the scene.

Preferably the or each heat source is located close to the target object of primary interest in the scene. This has the effect that atmospheric absorption in the sight path to the target, for example caused by smoke or fume, affects the measurement of the heat sources and the target object equally and is calibrated out by the system.

Preferably, a temperature range of the thermal imaging device is adjustable by the processor. Typically, this temperature range is adjustable by the processor in accordance with the known temperature of the or each heat source. This enables the system to be optimised and thereby produce the most accurate and highest resolution image of the scene as possible.

Generally, the thermal imaging device comprises a focal plane array (FPA) detector and preferably the FPA detector is an uncooled FPA detector. Preferably, the thermal detectors are bolometers and the thermal imaging system further comprises means for maintaining the temperature of the FPA detector at close to room temperature. Typically, the temperature of the FPA detector is maintained by means of a device operating on the Peltier principle.

Typically the imaging device is encased in a protective housing. This may include an internal heater, controlled by a thermostat, and provision for liquid cooling. The housing may also incorporate an air purging system and a protection window.

Preferably the or each heat source has a surface finish substantially identical to that of the target object of primary interest in the scene. In this case reflected radiation affects the measurement of the heat sources and the target object equally and is calibrated out by the system.

In situations where it is not practicable to mimic the target object's surface finish, preferably, the or each heat source is a black body source. In practice, the sources will not be perfect black bodies but may be close approximations with a high and stable emissivity due to a cavity structure or an appropriate coating.

An example of a thermal imaging system in accordance with the present invention will now be described with reference to the accompanying drawings, in which:-

Figure 1 is a schematic diagram depicting a thermal imaging system imaging a scene;

Figure 2 is an optical ray diagram indicating the position of the focal plane in a converging lens system; and

Figure 2b is a schematic representation of a thermal imaging device comprising a focal plane array detector.

The thermal imaging system 1 depicted schematically in Figure 1 comprises a thermal imaging device 2, connected to a processor 3 which in turn communicates with heat sources 6 and 7 and display device 4. The thermal imaging device 2 has a field of view (defined by dashed lines 9) which includes both heat sources 6 and 7 and an object 8. In this example, the object 8 comprises a channel 8a carrying molten metal 8b.

The heat sources 6 and 7 are designed to emulate black body sources, having a high and stable emissivity. The processor 3 communicates with the heat sources 6 and 7 to control the temperature of each heat source 6 and 7 and to know the accurate temperature of the heat source 6 and 7 at all times. The temperature of each heat source 6 or 7 may be measured by a variety of means including a contact sensor or an infrared thermometer. Each heat source may be set to the desired temperature by electronic means such as resistance heating means or a device operating on the Peltier principle, for example.

Thermal imaging device 2 receives the infrared energy emitted from all of the bodies within its field of view. The thermal imaging device 2 detects the incident infrared energy and converts it into electrical signals which are passed to the processor 3. The processor 3 uses this data to form a virtual thermal image of the scene, comprising an array of pixels. The image is "virtual" because it is not output from the processor 3. Each pixel corresponds to one of the detectors 15 in the thermal imaging device 2 and is indicative of the quantity of infrared energy incident

on that detector 15. This is a measure of the temperature of a portion of the scene viewed by the thermal imaging device 2.

The heat sources 6 and 7 are represented by two groups of pixels in the virtual image. The temperature indicated by each group of pixels is known to correspond to the known temperature of its respective heat source 6 or 7. The processor uses these pixels and the known temperatures and of the heat sources 6 and 7 to determine the offset between the actual temperature and the temperature indicated by the pixels. This correction is then applied to the entire virtual image, resulting in a calibrated temperature map 5 of the scene in which the temperatures of the various bodies are represented by different colours from the visible spectrum.

If the heat sources 6 and 7 have the same emissivity as the target objects of interest then the calibration calculation is as follows:

Let the uncorrected camera temperatures for the first heat source 6, the second heat source 7, and a target point be t1,t2 and t3 respectively, and the true, known temperatures of the heat sources 6 and 7 be T1 and T2 respectively. The true temperature of the target point T3 is then:

$$T3 = A \cdot t3 + B$$

where A and B are constants found by solving:

$$T1 = A \cdot t1 + B$$
$$T2 = A \cdot t2 + B$$

If the emissivities of the heat sources 6 and 7 and the target point are different but known to be E1,E2 and E3 respectively, then the calculation becomes:

E1 . f(T1) = a . f(t1) + b
E2 . f(T2) = a . f(t2) + b

where the functions f() are the Planck Radiation Function, multiplied by the spectral responsivity of the camera, integrated over the spectral bandwidth of the camera.

These two equations are solved for constants a and b, and then

E3. (T3) = a . f(t3) + b

is solved for f(T3)

T3, the true temperature of the target point, is then obtained by inverting the function f(T3).

The calibrated temperature map 5 is output by the processor 3 to the visual display unit 4. In the example shown in Figure 1, high temperatures are indicated by dark regions and cool temperatures by light regions. The heat sources 6 and 7, shown in the calibrated temperature map 5 as points 6' and 7', have different temperatures from one another. This need not be the case, but it is advantageous to arrange the heat sources in such a manner since the accuracy with which the image may be calibrated by the processor 3 is improved.

The calibrated temperature map 5 provides a quantitative measure of the temperature of each body within the field of view of the camera. The temperature of the object 8, or a portion of it, may therefore be accurately determined without the need for contacting thermometers or complex cooled FPA detectors.

The thermal imaging device 2 is shown in more detail in Figures 2a and 2b. Figure 2a indicates the position of the focal plane (FP) in a converging lens system. Light or infrared rays are depicted as straight solid lines. It can be seen that an object 12 is inverted and magnified by the lens 11 to form an image 13 at a distance f behind the lens

11. This distance f is the focal distance of the lens 11, and the plane in which the image 13 is formed is the focal plane (FP).

In this example, the thermal imaging device 2 comprises a focal plane array (FPA). In Figure 2b an array 14 of detectors 15 is shown to lie on the focal plane. Infrared rays (not shown) enter the thermal imaging device 2 through a lens 11 and form an image of the scene (in this case the object 12) on the array 14. Each detector 15 detects the amount of infrared energy incident upon it and converts the measured energy to an electrical signal which is communicated to the processor 3. As previously described, the processor 3 uses this data to generate a temperature map of the scene.

The detectors 15 are bolometers which may be operated at approximately ambient temperature. The bolometers may be fabricated from materials such as amorphous silicon or vanadium oxide using processes such as micro-machining or etching. Incident infrared energy causes the bolometer to heat up, thereby increasing its electrical resistance. The resistance of each bolometer is measured using a biassing means (not shown). Alternative types of detectors 15 may be used in place of bolometers, for example thermopile or pyroelectric detectors.

The thermal imaging system 2 is cased in a protective housing 16. This may include an internal heater, controlled by a thermostat, and also provision for liquid cooling. The array 14 of detectors 15 may be maintained at its operational temperature by a device operating on the Peltier principle. The housing 16 may also incorporate an air purging system and a protection window. These optional features are not shown in the Figures.

Conventional FPA thermal imaging cameras have limited signal drive capability and the read out must be located within a few metres of the camera. In the arrangement shown, the camera is connected on a short cable to a user interface box. This provides long cable drive capability

so that the processor can be mounted up to 1 kilometre from the camera. It also provides a convenient connection point at which to couple such a thermal imaging device with the processor 3. Also during system installation and commissioning, a local visual display unit may be connected at this point to view the received image, thereby assisting the setting-up of the apparatus.

CLAIMS

1. A thermal imaging system for quantitative thermal mapping of a scene, the system comprising:

a thermal imaging device;

a first heat source of known temperature and emissivity, located within the scene viewed by the thermal imaging device; and

a processor adapted to generate a calibrated temperature map of the scene from the data supplied by the thermal imaging device, based on the known temperature of the heat source.

2. A thermal imaging system according to claim 1 which further comprises a second heat source of known temperature and emissivity, located within the scene viewed by the thermal imaging device and wherein the processor is adapted to generate the calibrated temperature map from the data supplied by the thermal imaging device, based on the known temperatures of both the first and the second heat sources.

3. A thermal imaging system according to claim 1 or claim 2 which further comprises means for measuring the temperature of the or each heat source and communicating the temperature to the processor.

4. A thermal imaging system according to claim 3 wherein the temperature of the or each heat source is measured by a contact sensor.

5. A thermal imaging system according to claim 3 wherein the temperature of the or each heat source is measured by an infrared thermometer.

6. A thermal imaging system according to any of the preceding claims wherein the temperature of the or each heat source is adjustable by electronic means.

7. A thermal imaging system according to claim 6 wherein the temperature of the or each heat source is adjustable by resistance heating means.

8. A thermal imaging system according to claim 6 wherein the temperature of the or each heat source is adjustable by a device operating on the Peltier principle.

9. A thermal imaging system according to any of the preceding claims wherein the control of each heat source is effected by electronic circuitry local to that heat source.

10. A thermal imaging system according to claim 9 wherein a set-point temperature for control of the or each heat source is communicated from the processor to the electronic circuitry local to that heat source.

11. A thermal imaging system according to any of the preceding claims wherein a temperature range of the thermal imaging device is adjustable by the processor.

12. A thermal imaging system according to claim 11 wherein the temperature range is adjustable by the processor in accordance with the known temperature of the or each heat source.

13. A thermal imaging system according to any of the preceding claims wherein the thermal imaging device comprises a focal plane array (FPA) detector.

14. A thermal imaging system according to claim 13 wherein the FPA detector is an un-cooled FPA detector.

15. A thermal imaging system according to claim 14 wherein the thermal detectors are bolometers.

16. A thermal imaging system according to any of claims 13 to 15 which further comprises means for maintaining the temperature of the FPA detector at close to room temperature.

17. A thermal imaging system according to claim 16 wherein the temperature of the FPA detector is maintained by means of a device operating on the Peltier principle.

18. A thermal imaging system according to any of the preceding claims wherein the FPA detector is cased in a protective housing.

19. A thermal imaging system according to any of the preceding claims where in the or each heat source has a surface finish substantially identical to that of an object of primary interest in the scene.

20. A thermal imaging system according to any of claims 1 to 18 wherein the or each heat source is a black body source.

21. A method of generating a quantitative thermal map of a scene, the method comprising:

positioning a first heat source of known temperature and emissivity within the scene;

imaging the scene using a thermal imaging device; and

generating a calibrated temperature map of the scene, based on the known temperature of the heat source.

22. A method according to claim 21 further comprising positioning a second heat source of known temperature and emissivity within the scene and generating the calibrated temperature map of the scene based on the known temperatures of both heat sources.

23. A method according to claim 21 or claim 22 which further comprises measuring the temperature of the or each heat source and communicating the measured temperature(s) to a processor.

24. A method according to any of claims 21 to 23 which further comprises communicating a set-point temperature to the or each heat source, and thereby controlling the temperature of the or each heat source.

25. A method according to any of claims 21 to 24 which further comprises controlling a temperature range of the thermal imaging device, in accordance with the temperature of the or each heat source.

Fig. 1

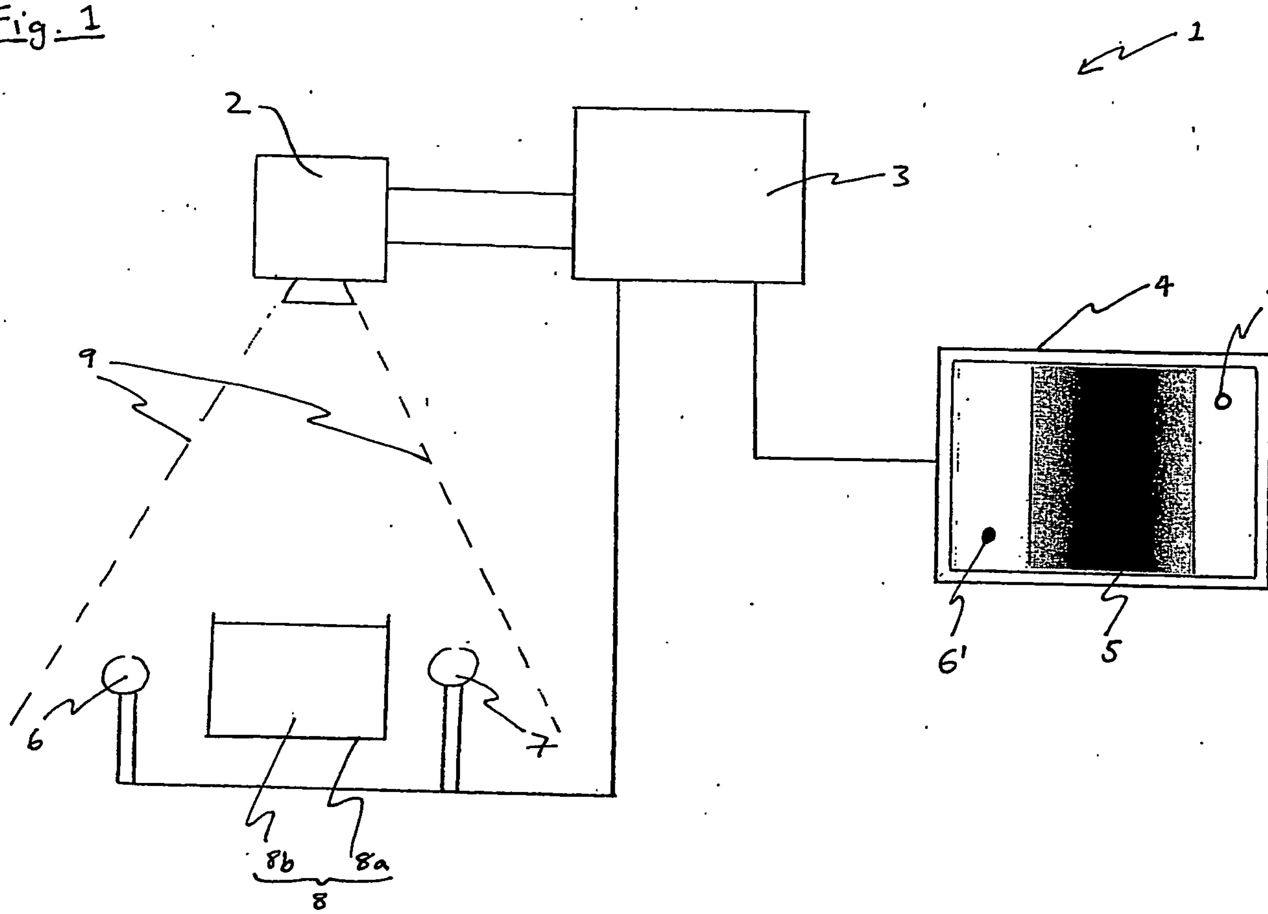

Fig. 2a

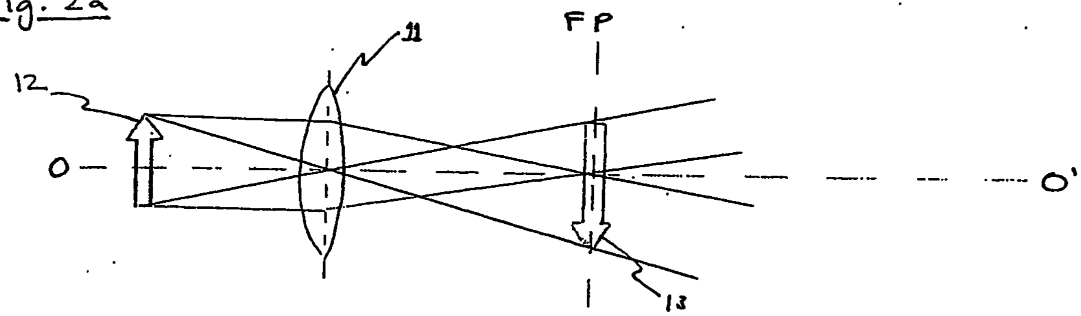

Fig. 2b